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Abrupt climatic changes during Termination III in southern Europe

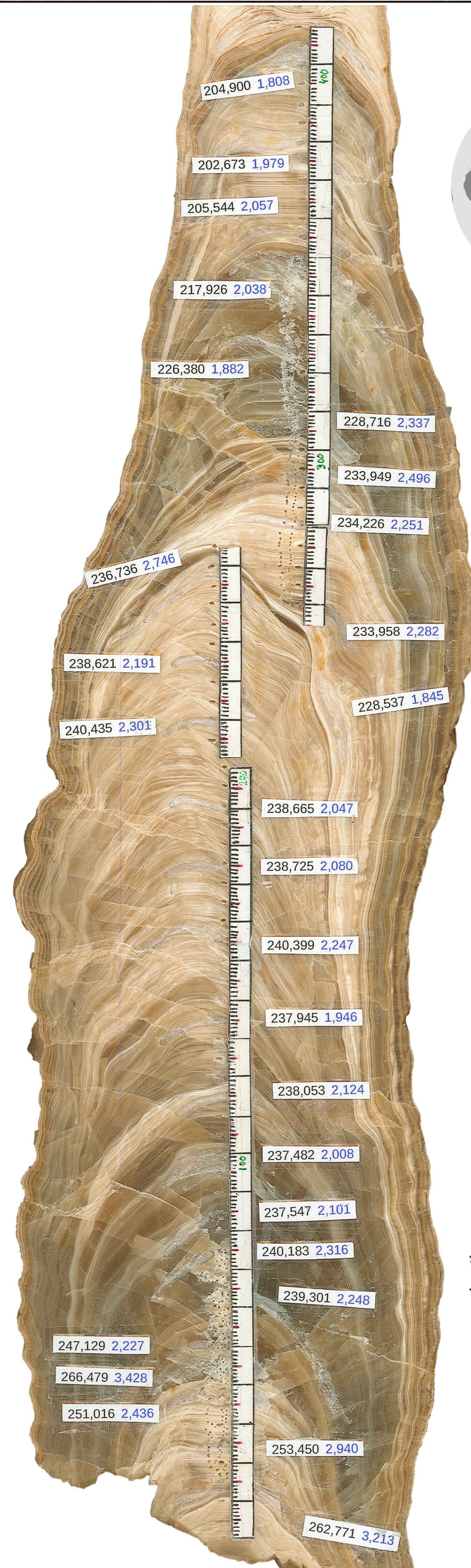
Carlos PÉREZ-MEJÍAS[1, 2], Ana MORENO[1], Carlos SANCHO[2], Miguel BARTOLOMÉ[1, 2], Heather STOLL[3], Isabel CACHO[4], Hai CHENG[5, 6, 7] and R. Lawrence EDWARDS[5].

[1]Department of Geoenvironmental Processes and Global Change, Pyrenean Institute of Ecology – CSIC, Avda. Montañana 1005, 50059 Zaragoza, Spain., [2]Earth Sciences Department, University of Zaragoza, C/Pedro Cerbuna 12, 50009 Zaragoza, Spain, [3]Department of Geology, University of Oviedo, C/Arias de Velasco, s/nº 33005 Oviedo, Spain, [4]GRC Marine Geosciences, Department of Stratigraphy, Paleontology and Marine Geosciences, Faculty of Geology, University of Barcelona, C/Martí i Franqués, s/nº, 08028 Barcelona, Spain , [5]Department of Earth Sciences, University of Minnesota, 310 Pillsbury Drive SE, Minneapolis, EEUU. , [6]State Key Laboratory of Loess and Quaternary Geology, Institute of Earth Environment, Chinese Academy of Sciences, Xian, China., [7]Institute of Global Environmental Change, Xian Jiaotong University, Xian,China

Introduction

The study of Terminations entails a good control of the timing of processes involved that can be partially explored by the identification of leads and lags between marine and terrestrial realms (Desprat *et al.*, 2007). Unfortunately, the sequence of events for older Terminations (eg. TIII) is not yet clear (Tzedakis, 2005), and, particularly, the response of the continental geosystems is not well constrained (Kwiecien *et al.*, 2014).

Here we present the first speleothem data from Ejulve Cave, Iberia (southern Europe) covering the TIII period, providing an unusually direct information of vegetation productivity throughout $\delta^{13}C$ variability as supported by a 3-years monitoring survey in the cave, with an excellent and independent chronological framework and a high-resolution climate reconstruction of this event.



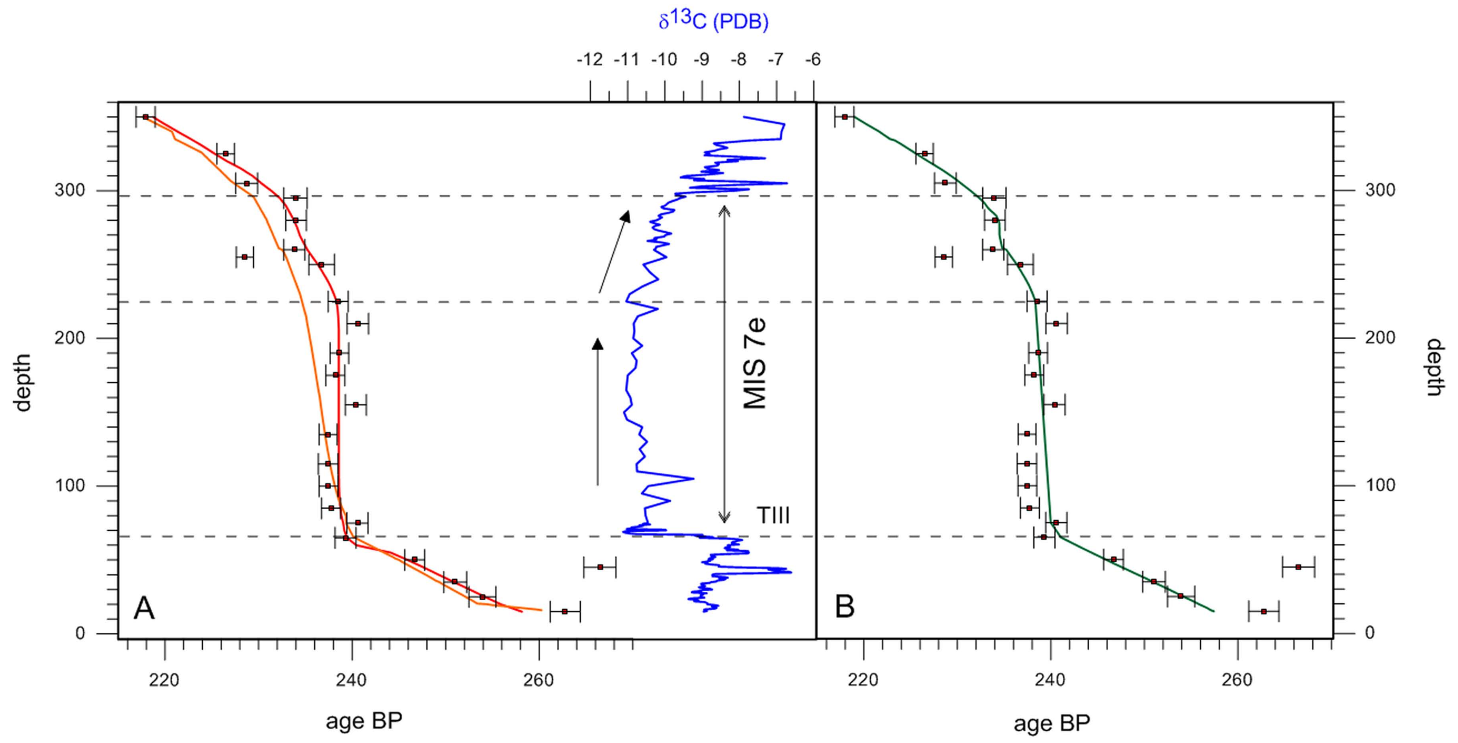
Study settings and results

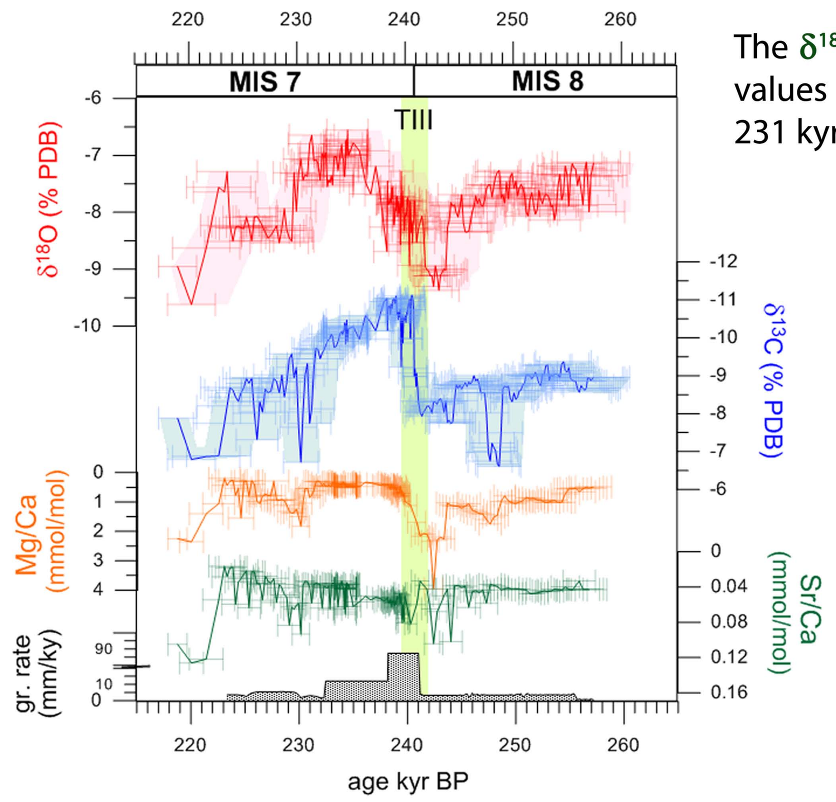
Ejulve cave is located in the Iberian Range, under a Mediterranean template climate with strong continentality. Average temperatures are 5ºC in winter and 22ºC in summer and mean annual rainfall is 600 mm.

The cave is developed in limestones and dolostones of Upper Cretaceous in age. The soil development at present-day is scarce, with a reduced epikarst thickness.

Vegetation cover in this area is composed of *Quercus ilex*, *Genista scorpius*, *Thymus vulgaris*, *Rosmarinus officinalis* and *Pinus halepensis*.

The **chronological framework** is constrained by 24 dates, two of them are outliers. The preliminary attempts with OXCAL software (orange line) using deposition model and procedures described in Ramsey (2008) show a low slope, without crossing the datings from 140 mm in advance, even deleting the outliers and using different "k" values. The model of StalAge (Scholz and Hoffmann, 2011) (red line) established an non-realistic growth during MIS-7e with a vertical line. Final model (green line) is built using a combination of StalAge software and linear interpolation.





The $\delta^{18}O$ show a range of variation of 2.8 ‰, with low values during 244-242 kyr and an increasing trend until 231 kyr.

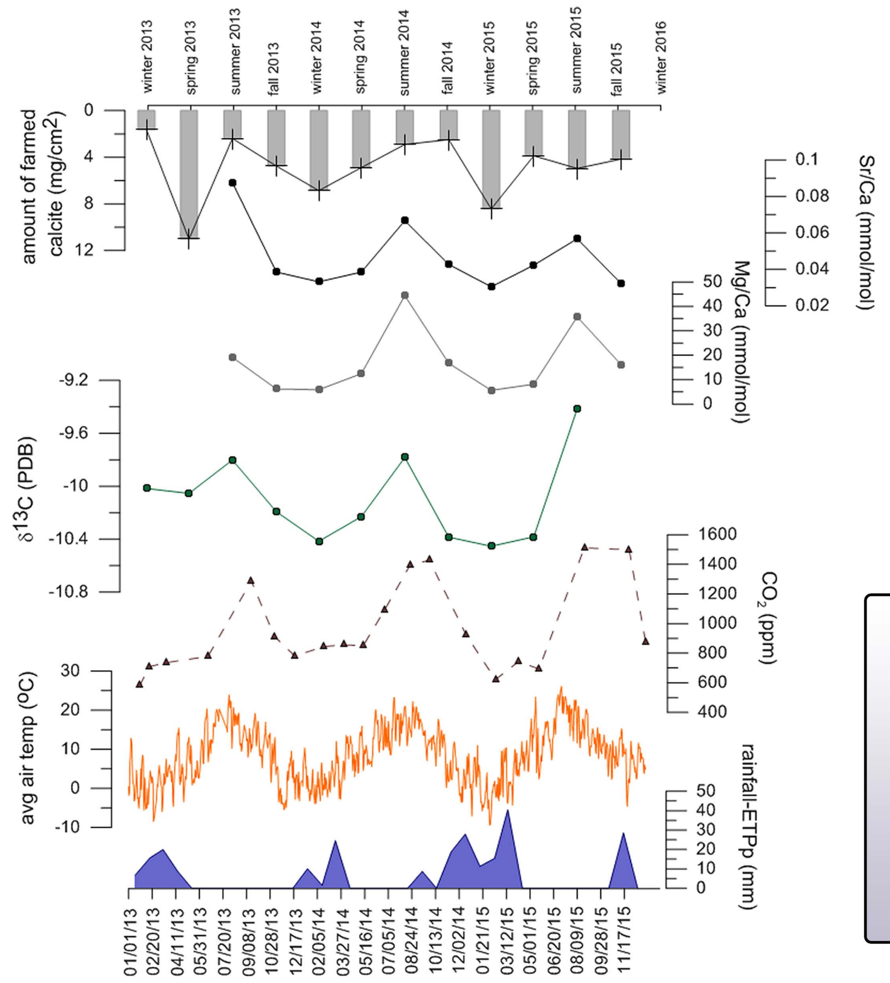
The $\delta^{13}C$ variation is 4.52 ‰, with minimum values reached at the onset of MIS-7e and maximum previous to TIII inception.

The growth rate reaches its maximum (87mm/kyr) at 238 kyr coinciding with MIS-7e and keeps high (12mm/kyr) until 233 kyr, descending to rates close to 5 mm/kyr afterwards.

Both Mg/Ca and Sr/Ca show a similar pattern exhibiting higher values in correspondence with high $\delta^{13}C$ values.

Interpretation of $\delta^{13}C$ in farmed calcite

Previously, some drips and their related farmed calcite were selected to evaluate the relationship between environmental and carbonate features.



The results of stables isotopes and metal ratios in farmed calcite show a clear seasonal pattern.

SUMMER
- $\delta^{13}C$, Mg/Ca and Sr/Ca of farmed calcite
- CO_2 inside the cave
- Air temperature outside

Null moisture availability
Low amount of farmed calcite

FALL, WINTER SPRING
- $\delta^{13}C$, Mg/Ca and Sr/Ca of farmed calcite
- CO_2 inside the cave
- Air temperature outside

Effective moisture (net rainfall)
Higher amount of farmed calcite

In this region, the available moisture rather than temperature, is the key limiting factor for stalagmite growth. In summary, **high values of $\delta^{13}C$** with **high trace element ratios** are interpreted as **aridity**.

Discussion

The $\delta^{13}C$ profile in Ejulve Cave during MIS-7 exhibit two phases:

- **MIS-7e-I:** has humid conditions, with fast growth until 238 kyr and a second peak until 233 kyr, coeval with weaking summer monsoon in Sanbao (e).
- **MIS-7e-II:** clear trend to dry conditions between 232-231 kyr leading to MIS-7d. The structure that remarks the onset of MIS-7d is similar to Spannagel cave (Alps) (Spötl *et al.*, 2008) (g) and Kesang cave (China) (f).

In previous data extracted from pollen, different forest periods were stablished in Europe (o,p,q) (Follieri *et al.*, 1988; Tzedakis *et al.*, 2003; Desprat *et al.*, 2006) during late MIS-8 and early MIS-7 associated with the insolation peak, coinciding with low values of $\delta^{13}C$ in Ejulve cave (d).

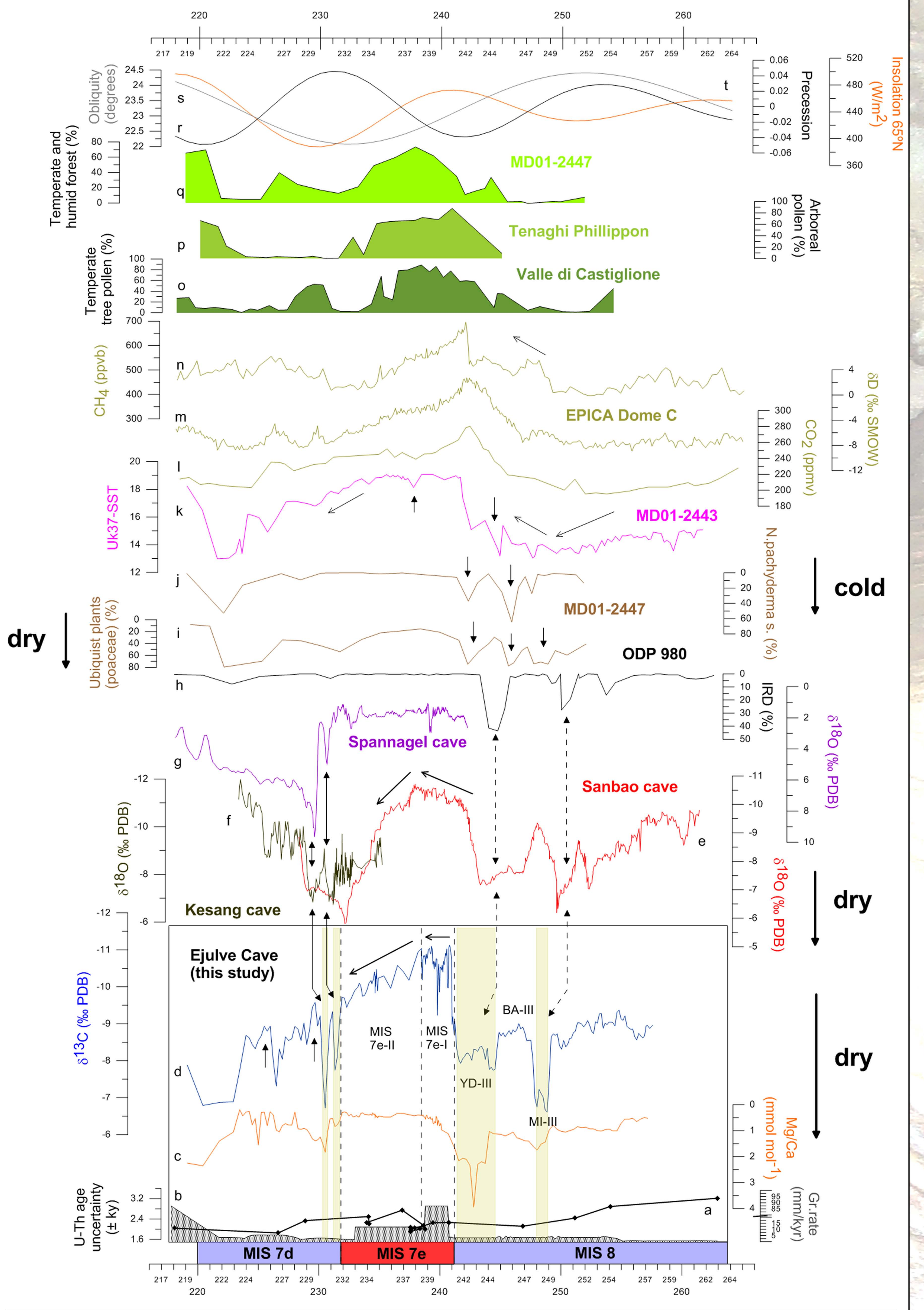
We identify two phases in MIS-7, attending to water availability: MIS-7-I (more humid) and MIS-7-II (with trend to dry)

The liberation of icebergs to the ocean in three episodes, during 253, 249 and 244 kyr in ODP 980 (McManus, 1999) (h) affects the Atlantic Meridional Overturning Circulation (AMOC), thus weakening the heat transport to lower latitudes and subsequently producing dry conditions in Ejulve Cave and alterations in the summer asian monsoon (Cheng *et al.*, 2009) with dry conditions in Sanbao Cave (e) during the Mystery Interval-III. The fluctuations are recorded also in the Iberian Margin, showing both dry (*poaceae*) and cold (*N. pachyderma s.*) conditions (i,j).

With a rising insolation and an ice volume not so high, the iceberg discharges ceases and a humid period starts in Ejulve, the summer monsoon strengths and shapes also a humid period in Sanbao during the BA-III (d,e). This period finished abruptly, with cold conditions in Atlantic sea (Martrat *et al.*, 2007) (k) remarking the onset of the YD-III dry period.

The increasing in CO_2 levels in Antarctica (Lüthi *et al.*, 2008) provoke a gradual warming, manifested by δD (Jouzel *et al.*, 2007) (m,l) triggering also an abrupt peak in the CH_4 (n) probably due to the retreat of the ice sheet and subsequently higher methane emissions periglacial wetlands (Loulergue *et al.*, 2008).

Now with low ice sheet, temperature in the North Atlantic increasing, summer monsoon reinforcing, and unusually high CO_2 levels enhancing photosynthesis (thus, vegetation activity) worldwide, the humid MIS-7e period begins.



The weakened signal in summer monsoon in Sanbao Cave, China, and within age uncertainties, coeval to dry conditions in Ejulve, SW Europe, reinforce the idea of **YD-III as a global process not limited only to monsoon systems.**

cperez@ipe.csic.es

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